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ZERO ENERGY UNIVERSITY BUILDINGS ENERGY PERFORMANCE EVALUATION OF FACULTY OF ARCHITECTURAL ENGINEERING IN TRIPOLI'S BRANCH

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One of the fastest growing trends in educational building design is Net Zero Energy buildings (ZEB). There are several buildings, either completed or under construction, that are committed to achieve this incredible level of energy efficiency [4]. The Faculty of Architecture building in BAU University is chosen as a case study to evaluate the energy performance in similar buildings in comparison with zero energy design strategies. The study used the findings from the analysis to identify and correct problem within the building. The aim of the research is to change the faculty building from an energy consumer to an energy producer, in order to reach a zero-energy educational building. The fundamental design strategies to achieve zero energy building will be presented in a second part in order to use as an evaluation criteria of the case study building performance. The efficiency evaluation and comparison of the envelope criteria with the thermal standard reference adopted by the Order of Engineers and Architects in Beirut, led to identify the appropriate solutions needed to upgrade the thermal performance of the building envelope, and to determine the innovative solutions in the field of renewable energy.

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Abstract

One of the fastest growing trends in educational building design is Net Zero Energy buildings (ZEB). There are several buildings, either completed or under construction, that are committed to achieve this incredible level of energy efficiency [4]. The Faculty of Architecture building in BAU University is chosen as a case study to evaluate the energy performance in similar buildings in comparison with zero energy design strategies. The study used the findings from the analysis to identify and correct problem within the building. The aim of the research is to change the faculty building from an energy consumer to an energy producer, in order to reach a zero-energy educational building. The fundamental design strategies to achieve zero energy building will be presented in a second part in order to use as an evaluation criteria of the case study building performance. The efficiency evaluation and comparison of the envelope criteria with the thermal standard reference adopted by the Order of Engineers and Architects in Beirut, led to identify the appropriate solutions needed to upgrade the thermal performance of the building envelope, and to determine the innovative solutions in the field of renewable energy.

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INTRODUCTION

Evaluation of the criteria in the definition framework and selection of the related options becomes a principle to set « Net Zero Energy Buildings » definitions in a systematic way. The balance concept is central in the definition framework and two major types of balance are identified, namely the import/export balance and the load/generation balance. In concession between the two, a simplified monthly net balance is also described. Concerning the temporal energy match, two major characteristics are described to reflect a Net (ZEB's) ability to match its own load by on-site generation and to work beneficially with respect to the needs of the local grids [2]. Therefore, the zero-energy building criteria can be divided in two aspects in order to determine a methodology in energy efficiency evaluation:

Energy-efficient Buildings: Regardless of the sources, the energy efficiency of buildings is covered- the reduction of energy demands-is a central element of any sustainable strategy.

Self-sufficient buildings: At first glance, and considering these degrees of energy efficiency, a building that can supply its own energy seems to be just a step away. A self-sufficient building, i.e. a building that isn't connected to energy infrastructure, guarantees continuous energy supply based on the size of the building's own, typically solar energy system, and particularly of energy storage devices, without reverting to other, external resources [1].

Educational buildings are good candidates for Net Zero Energy because they already use less energy than most commercial building types. They use only 33% the energy of hospitals per square foot and 51% the energy of office buildings per square foot. Collectively, Educational buildings use only 17% of total non-residential building energy. A combination of factors addresses this type of buildings as to be less-energy users:

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- Less use during the summer
- Extensive vacation periods when building systems are in unoccupied mode
- Shorter period of use in the typical day
- Minimal process loads [4].

In addition to having less energy use intensity, educational buildings have another advantage in the race towards Net Zero Energy. They are typically more receptive to the application of renewable energy because they have larger sites (except in a few denser urban conditions), large roof areas relative to their gross floor area, and the fact of being own by entities with a long-term investment horizon. The aim of this study is to convert the Architectural department in BAU (Beirut Arab University) Tripoli campus to a Zero Energy building. Before that, the fundamental design strategies of zero energy building are determined to specify the framework and methodology of the evaluation of the case study.

FUNDAMENTAL DESIGN STRATEGIES TO ACHIEVE ZERO ENERGY

In order for an educational building to achieve Zero Energy, it must get all the basics of sustainable design right. The checklist used to evaluate the case study consists of the following elements: 1) Orientation/Massing, 2) Envelope, 3) Daylighting, 4) HVAC and controls, 5) Electrical lighting and controls 6) Occupant Behavior and Plug Loads. Each element has the capability of reducing building energy use by 10% or more [4]. Conversely, if the design team ignores any element, it may over compensate with the excessive design or cost of one or more of the others elements.

- Orientation/Massing: By choosing the appropriate orientation and facilitating daylight harvesting, we can reduce the heat load on the building in the summer. Whenever possible, we seek to obtain a reasonable ratio of surface area to volume, without denying daylight access to learning spaces. Combining optimum orientation and massing can easily yield 15% energy savings [4].
- Envelope: Current building codes require continuous insulation, which is a significant improvement in comparison with previous codes without that provision. Referring to the thermal standard for buildings in Lebanon proposed by ALMEE and Order of Engineers, the minimum performance criteria ought to be met in the non-residential building envelope located in the Coastal climatic zone. The goal in-relation with exterior walls is to achieve an effective U-value (thermal transmittance) of 1.26. Routinely, we exceed building code required for roof insulation, using U-0.71 (Table1) [6]. For any building with fenestration, the maximum allowable Reference Window to Wall Ratio (WWR-ref presented in Table 2) was determined by using improved glazing and architectural shading devices to control the solar cooling load and to optimize the beneficial solar heat gain during the heating season [6]. Providing a well-designed, constructed, and insulated envelope can yield energy savings of 15% over minimal code compliant construction [6].
- Daylighting: Because electrical lighting can consume as much as 20% of total site energy use, it is important to do everything possible to minimize that. At first, by substituting free daylight for costly electric light during the day. As the educational building schedule coincides well with daylight hours, minimizing electric lighting is easily accomplished [4].

Climatic Zone	Building category	U-value Roof	U-value Wall	U-value Window & Skylight	U-value Ground Floor Exposed*	Semi-exposed**
1 Coastal	1 Residential	0.71	1.60	5.80	1.70	2.00
	2 N Residential	0.71	1.26	5.80	1.70	2.00
2 Mid Mountain	1 Residential	0.63	0.77	4.00	0.77	1.20
	2 N Residential	0.55	0.65	3.30	0.70	1.20
3 Inland Plateau	1 Residential	0.63	0.77	4.00	0.77	1.20
	2 N Residential	0.55	0.65	3.30	0.70	1.20
4 High Mountain	1 Residential	0.55	0.57	3.30	0.66	1.00
	2 N Residential	0.55	0.57	2.60	0.66	1.00

Table 1: Reference Thermal Transmittance values per component vs. Lebanese Climatic zone.[6]. Category 1:Residential Category 2: Non-Residential

Climatic Zone	Building Category ¹	Maximum Effective Fenestration Ratio (EFR _{ref})
Zone 1: Coastal	1	11%
	2	10%
Zone 2: Western mid-mountain	1	13%
	2	13%
Zone 3: Inland Plateau	1	11%
	2	11%
Zone 4: High Mountain	1	16%
	2	21%

Table 2: Reference Effective Fenestration Ratio vs. Lebanese Climatic zone [5].

- **Electrical lighting and controls:** The second step to reduce energy use related to electric lighting is to minimize lighting power density (LPD) while still maintaining comfortable interior lighting. This is done through careful fixture selection and placement [5]. Automated controls that turn off electric lights such as occupancy/vacancy sensors, timed sweeps, and dimming in response to daylighting all can be used to reduce the time during which electric lights are turned on.
- **HVAC and controls:** The combination of space heating, ventilation, and air conditioning consume more energy than any other component/s in an educational building. The integrated design of these systems is therefore critical to improve energy performance. Air delivery through displacement ventilation has the potential to reduce energy use slightly while greatly improving both indoor air quality and acoustics [4].
- **Occupant Behavior and Plug Loads:** Educational building designers and administrators are well aware of the challenges posed by occupant behavior. Nowhere is this more evident than in the effort to control potentially excessive and wasteful plug loads.
- **Renewable energy:** Renewable energy sources in an educational building or site are necessary in order to achieve Net Zero Energy, but vital care should be taken in selection. Choosing the sources should be made in consideration with other building systems, local climate, and financial constraints such as rebate availability [4].

In addition to few other key strategies, one such as displacement ventilation, these active energy efficiency strategies are essential to achieve the building's energy goals. In Order to reach the architectural department's net-zero goals in BAU campus, the research analyze the current state of the building through the previous strategies. Alongside with the passive and active energy savings features discussed previously, the solar energy creation of the photovoltaic arrays will be essential for the department to reach its ambitious net-zero goal.

INTERPRETATIONS STRATEGIES OF THE ARCHITECTURAL FACULTY BUILDING IN BAU TRIPOLI CAMPUS

In a transit from a theoretical to a practical strategy, the architectural department in BAU University-Tripoli campus is chosen to be the case. The analysis of the building background, energy demand, used material, and energy efficiency are essential toward converting the conventional building to a zero energy building.

Background of Case study

BAU Tripoli Campus is located in Basateen Al Mina area. The project Land spans an area of 15.540 m² with 35.594 m² as built area. The University campus consists of an administration building and five different faculties (Figure 1.). The architectural faculty building contains lecture and studio room. The three-story, 2,211-m² building is chosen to evaluate the energy-efficiency in such typical educational building.

Case study evaluation with proposed improvement toward zero energy building

Referring to previous design strategies to achieve a zero energy building, the case study building is evaluated. By comparing the thermal standards and thermal numbers in the project, the study proposed some interventions that can be added to the building to achieve a zero-energy state.

The structure used in the project is based on reinforce concrete structure with masonry block walls as internal wall partitions. The external walls consist of double walls with a 2cm air cavity. The cladding used in the building is Saw-cut polished stone that covered 100% of the building envelope (Figure 4). Comparing the U value of the current building envelop with the reference value (Table 3), we can conclude that the U-values of the external wall, roof and glazing are below requirements; hence, they are considered not suitable with non-residential building envelop thermal standard.

BAU Tripoli Campus	
Architect	Said Kadi Jazairi
Location	Tripoli, Lebanon
Date	2009
Area	35.594 m ²
Client	BAU university
Climatic zone	Coastal

Table 3: Case study information

Envelop

The maximum allowable effective fenestration ratio was previously presented from a review of the current average fenestration ratios, belonging to existing buildings in Lebanon, and the economical use of improved glazing and architectural shading devices to control the solar cooling load and to optimize the beneficial solar heat gain during the heating season.

Orientation/Massing

The design team orientated the building to face south and elongated the east-west axis to maximize solar heat gain (Figure 2). The building orientation, combined with engineered window overhangs and fenestration, contribute in the solar heat gain in winter, solar load avoidance in summer, and the maximized use of natural light. The layout of spaces is designed in accommodation with orientation. (Figure 3) illustrates the layout; Equipment rooms and services areas are located on the south side of the building. The sunspaces represented by the corridor in the first and second floor are located on the south side.



Figure 1: Architectural Faculty Building in BAU Tripoli Campus.

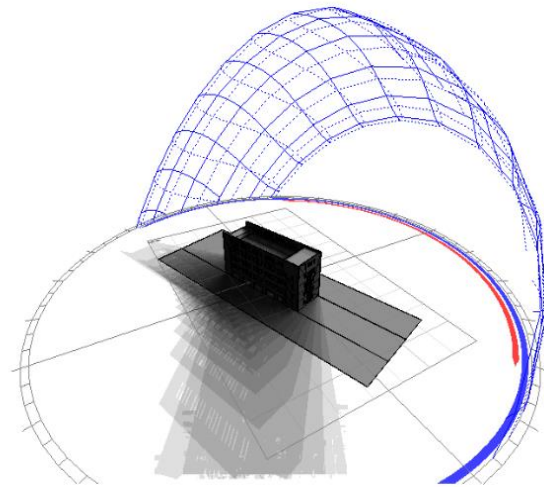


Figure 2: Architectural Faculty building through the solar path and shadow range.

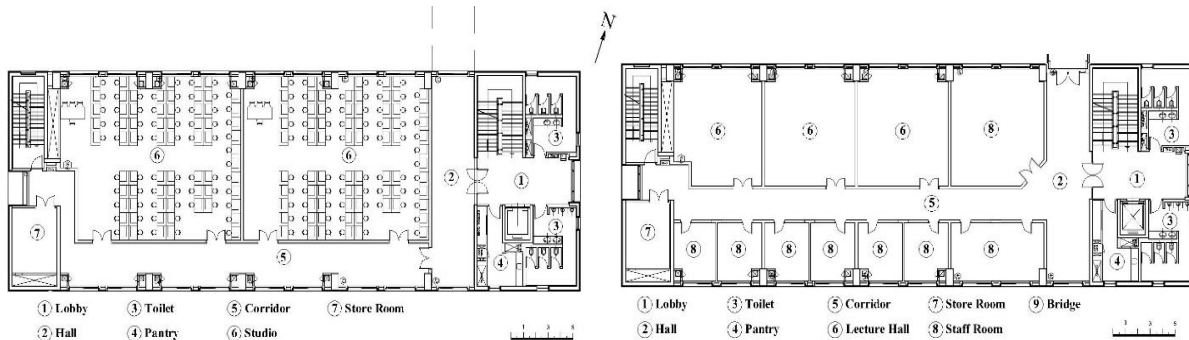


Figure 3: First and third floor plans.

The EFR value for the proposed building is calculated using the following Equation:

$$EFR = \frac{\sum (A_{wi} \times SC_{wi} \times ASF_{wi})}{\sum A_v} + 2 \frac{\sum (A_{si} \times SC_{si})}{\sum A_h}$$

A_{wi} = Area of the individual window (m²)
 SC_{wi} = Shading coefficient of the individual window
 ASF_{wi} = Architectural shading factor of the individual window
 A_v = Area of all vertical surfaces (opaque walls + windows) (m²)
 A_{si} = Area of the individual skylight (m²)
 SC_{si} = Shading coefficient of the individual skylight
 A_h = Area of all horizontal surfaces (roofs + skylights) (m²) [5]



Figure 4: BAU campus under construction and stone cladding.

Building envelop construction and Thermal Properties comparing to the reference.				
Envelope Component	Construction (outside to inside)	U value (W/m ² .k)	U reference (W/m ² .k)	R value (m ² .k/W)
Exterior walls	Stone (3cm) + steel fixation (5cm)+ Plaster (1.5 cm) + hollow block(15cm)+ air gap(5cm)+ hollow block (10cm)+plaster (1.5 cm).	1.33	1.26	0.75
Interior walls	Plaster (1.2cm)+hollow block (10cm)+Plaster (1.2cm)	2.5		0.4
Windows/doors	Double Glazing	3.3	5.8	0.30
Floors	Plaster(0.5cm)+Hollow core prefabricated slab (32cm)+screed(5cm)+Terrazzo Tiles(3cm)	1.78	1.7	0.56
Roof	Plaster(0.5cm)+Hollow core prefabricated slab (32cm)+Stairboard insulation (5cm)+screed(5cm)+Terrazzo Tiles(3cm)	0.39	0.71	2.5

Table 4: Building envelops construction and Thermal Properties comparing to the reference.

Building Fenestration			
Wall Location	Fenestration area	Total Wall Area	Fenestration to Total wall Area Ratio
North	229 m ²	1159.3 m ²	0.19
South	229 m ²	1159.3 m ²	0.19
East	47 m ²	363m ²	0.13
West	37 m ²	399m ²	0.09

Table 5: Building Fenestration

(Table 4) summarizes the EFRs for the four building facades. The EFRs in the north and south façade scores 19%; hence, we can notice that openings exceed the required minimum level. Thus, it is necessary to add external shading device to lessen the levels.

Daylighting

Both, light and heat from the sun help and hinder energy conservation in different ways. In the case study building, spaces with high-occupant usage (including studios and lecture rooms) are located on the North at the first and second floors. Natural light can contribute to lighting needs without gaining heat.

The introduction of new shading or light shelf elements (figure 5), mainly above openings of the third floor, controls daylighting and balances the solar heat-gain. Lowering solar gains and reducing cooling loads allow downsizing of cooling system equipment. Nevertheless, the establishment of sunshades or light shelves at the south façade, and shading fins at the east and the west faces can minimize the fenestration ratio and control excessive sunlight. Hence, allowing the glazing to be tuned more for temperature differences.



Figure 5: External shading devices proposed for south facade

HVAC and controls

All smaller windows in classrooms and offices can be opened manually. The windows are designed to create a cross ventilation effect through the corridor windows, supplying natural ventilation when outdoor conditions permit (Figure 6). An effective suggested strategy to maintain control is using heat recovery chillers with net metering. The heat recover chiller provides condenser water that heat and reheats throughout the building while simultaneously producing chilled water as a useable byproduct. The heat recover chillers, as an energy-efficient system, contributes up to 23% energy savings [10]. Therefore, in the case study building, chillers could be switched from ordinary cooling towers Marine Chiller type which using seawater for cooling to saving up to 30% of the power of cooling consumption.

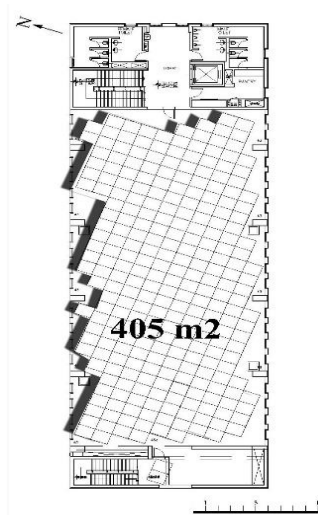


Figure 6: Classroom plan

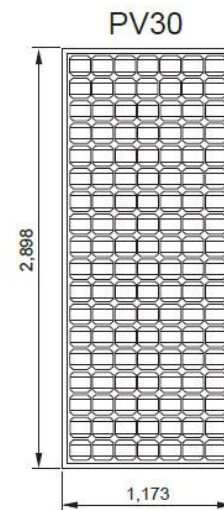


Figure 7: PV dimensions

Electrical lighting and controls

Other important strategies involve lighting. All of the occupied spaces can use occupancy sensors that reduce artificial lighting when spaces are not occupied and with sufficient daylight penetrating the rooms. In addition, the building conserves energy with LED lighting fixtures, that scores up to 5% of the building's energy savings [11].

Renewable Energy

The aim is to convert the building from an energy consumer (based on burning petroleum products) to an energy supplier (based on on-site renewable sources). Referring to the annual bill of the university energy load, the seasonal and monthly variations indicate the increasing of energy consumption in September month (Figure 8).

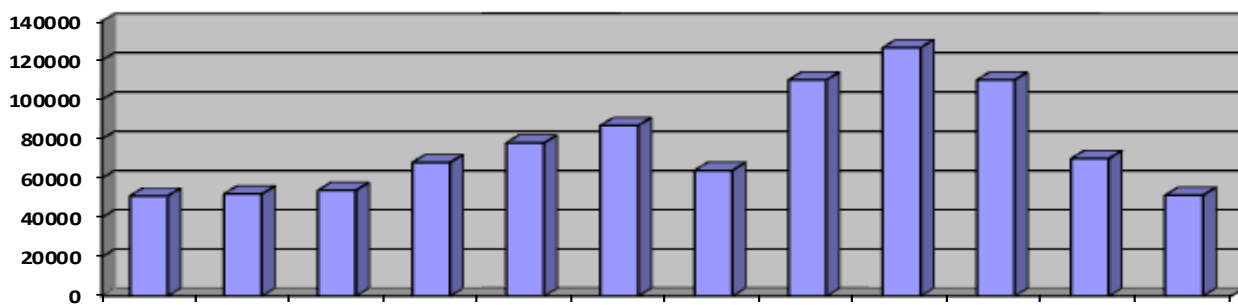


Figure 8: Average monthly energy consumption of BAU Tripoli campus building (bills) in kWh during 2013 [Researcher]

The Faculty of Architecture building covers an area of 3000m² from 35594m² of the whole university area. It is supposed to use 8.5% of total university's electricity. In September, the total electricity consumption scores the highest value between months; 126440KW (Figure 9). The building scores the highest consumption (126440x0.085) 10747.4KW. However, the electrical bill does not cover the overall electrical consumption due to the blackout in electricity. Hence, the previous calculations should be doubled to give the precise monthly electricity consumption; (10747.4x2) 21494.8KW/month. In order to cover this energy load, the solar panel and wind turbine are chosen as available local renewable energy systems.

Solar Panel System

To calculate the needed number of photovoltaic panels and the quantity of electricity ought to be generated by the panels in "watt", we should identify the building's actual need of electricity per day. The high-energy usage by the building is scored in September as previously mentioned, and the peak energy to cover is (21494.8 Kw/30) 716.4 Kw/day.

العدد	المدة	الطاقة المستهلكة (KWH)	الطاقة المستهلكة (KVARH)
226808	227,026	711,099	49,092
179212	208,499	606,970	45,308
47,596	18,527	104,129	3,784
47,596	18,527	104,129	3,784
48,072	18,732	105,170	3,522
0	80	112	320
0	1,496,960	11,779,040	1,223,040

Figure 9: Electrical consumption of BAU Tripoli campus building (bills) in September [Researcher].

Model		PV15	PV20	PV30
Peak Power ¹	Wp	225	300	460
Module Efficiency ²	%	15.0	14.3	15.3
Number of Cells		63	84	126
Maximum Power Voltage (Vmpp)	V	30.8	41.1	61.7
Maximum Power Current (Impp)	A	7.3	7.3	7.5
Open Circuit Voltage (Voc)	V	38.9	51.9	77.9
Short Circuit Current (Isc)	A	8.0	8.0	8.0
NOCT ³	°C	44.6	44.6	44.6
Cell Type		Monocrystalline Silicon		
Maximum System Voltage	Voc	1,000		
Power Temperature Coefficient	% / °C	-0.509		
Current Temperature Coefficient	% / °C	0.043		
Voltage Temperature Coefficient	% / °C	-0.337		
Safety Classification		Class II		

Figure 10: Electrical Specification of the Clearline PV module

Multiply the used Watt-hours per day by 1.3 (the energy lost in the system) to get the total Watt-hours per day (must be provided by the panels).

$$716.4 \text{ Kw} \times 1.3 = 931.4 \text{ Kw}$$

We have to consider "panel generation factor" which differs at each site location. In Lebanon, the summer day is of a long day length and high brightness intensity, amounts to average 7 hours per day (<http://www.upsaps.com>). Calculate the total Watt-peak rating required for PV modules. Divide the total Watt-hours per day needed from the PV modules by 7 to get the total Watt-peak rating needed.

$$931.4 / 7 = 133 \text{ Kw}$$

To calculate the number of PV panels, we divide the answer obtained by the rated output Watt-peak of the PV modules (Figure 7,10), and then increase any fractional part of result to the next highest full number to get the number of PV modules required. $133,000 / 460 = 289.1$ modules. Referring to the previous calculation, the number of PV panels needed to cover the electricity bill to the Faculty of architecture building is 289 panels. Therefore, the area needed to place the desirable modules covers $(289 \times 3.2) 946.7 \text{ m}^2$. However, the maximum roof area available is 405 m² and we are able to fix 182 PV panel modules (Figure 11). Thus, the proposed solar panel system can cover 42% of the energy consumption.

Vertical Axis Wind Turbine

The whole unit consists of pillar, wind generator, storage batteries and inverter / controller. The Mill, pushed by wind at speed from 4m/s to 25m/s, rotates and generates AC energy power. Then, the power is converted to DC form by the charging controller, and saved in storage batteries. The average wind speed all over the year is 6-6.5m/s in the case study location (Figure 11). From the power curve of the 10 kw VAWT we found that the power corresponding to 6.5 m/s is 1.5 kw (Figure 13). The average wind blowing time over the year is calculated to be around 12 hours / day. Total daily energy is $1.5 \text{ KW} \times 12 \text{ hours} = 18 \text{ KW/day}$. Therefore, the proposed Wind turbine system can cover 2% of the energy consumption.

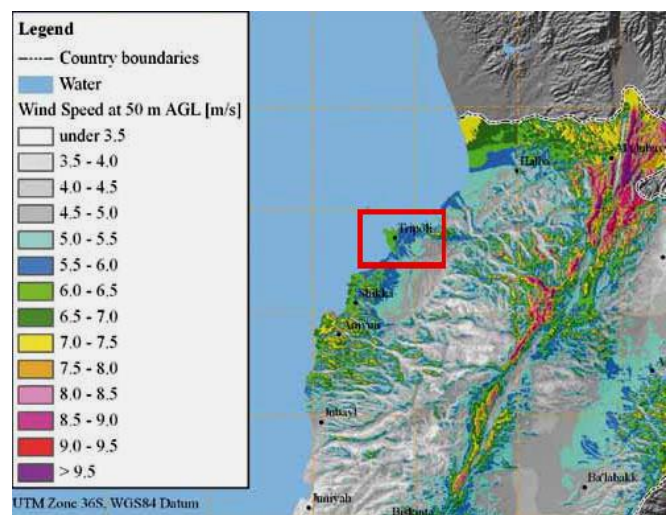


Figure 11: Wind map of the North Lebanon [7].



Figure 12: Power curves for 10 KW vertical Axis Wind Turbine [11].

CONCLUSION

In order to optimize the energy performance of existing buildings, applying the most cost effective retrofit technologies is important to achieve enhanced energy performance while maintaining thermal comfort to the occupants. An energy audit should be done at first to determine the energy inefficiencies taking place within the building systems, mainly for the envelope, by comparing the thermal specifications of the case study building with the Lebanese thermal standards in the coastal zone where Tripoli city is located. The department of Architecture in BAU University in Tripoli city-Lebanon – as a study case- is analyzed to maintain an energy consumption reduction plan through several design strategies. Referring to this, specific strategies are adopted to achieve a zero energy. Table 5 summarizes the previous listed adopted strategies:

Proposed retrofitting strategies with the energy reduction	
Retrofit Design strategies	Energy reduction
1) Envelope	28%
2) Upgrading HVAC	23%
3) Electrical lighting	5%
4) Renewable Energy	44%
Total reduction	80%

Table 6: Proposed retrofitting strategies with the energy reduction

The building envelope is considered an important factor that affects the energy consumption of an existing building. The building-envelope elements studied in this research (WWR, thermal transfer, materials specification, orientation) can affect directly and in-directly other factors; such as heating and cooling systems, passive design, energy consumption, water management, lighting systems and renewable energy. These elements are studied to set the best retrofit suitable strategies to be used. The building envelope consists of walls, floors, fenestration and roofs; for walls and floors, insulation can be applied as well as other alternative fixation options. External Lighting systems as well can lead to great energy saving, especially by proper integration of daylight and artificial light with automation systems that can cause reduction in light energy consumption by 35%.

Adding building integrated photovoltaic cells can be another option for generating electricity. 10KW Vertical-axis Wind turbine is selected as another renewable energy source to transform the building from an energy consumer to an energy supplier.

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